DOCUMENTATION OF STONE AGE ARTIFACTS

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ABSTRACT:

In certain areas, such as the Middle Rhine Region in Germany, stone age artifacts can be found in large quantities on top soils of farmland. Since more than 40 years amateur archaeologists, in cooperation with the Bodendenkmalpflege (curators for archaeological monuments) in Mainz, are collecting these objects and store them, after registration, in their homes. In a joint research project, archaeologists and engineers have developed a procedure to document these artifacts and make them available in a virtual collection. A GOM ATOS II close range scanner, operating on a light pattern triangulation principle, is used to record a complete 3D point cloud representation of the stones' surfaces. Considerable effort has been taken to increase the speed of the recording process which involves the execution and combination of up to a dozen of scans from different aspects. Subseqently, the single scans have to be merged using two-dimensional and three-dimensional reference points. Following a 3D meshing procedure, the surface points are thinned. The 3D virtual object can be linked with a database containing further information such as material, usage, weight, place of present storage, etc. Coordinates for the locations where the objects were collected are also stored in order to create a GIS. Certain geometric properties such as size and volume can be derived from the virtual object and introduced into the database. This policy makes the artifacts of the private collectors available to archaeological science and allows objective studies and comparisons. Interactive 3D visualization can be used to inspect and evaluate the artifacts when the data are distributed on digital data storage media. A special interactive viewer was designed for use in the Internet. Additional features such as visualization tools for local curvature and an automatic derivation of outlines for 2D drawings were developed in order to supply objective tools for inspection and publication.

1. MOTIVATION

The Middle Rhine Valley between Bingen and Koblenz has recently been added to UNESCO's World Heritage List of cultural landscapes. The Neuwied Basin north of Koblenz is a rich archaeological area. Evidence of human settlement is present very early in this region. Since the 1960s systematic excavations have been undertaken here on different sites. Miesenheim I (494.000 B.P.) and Kaerlich Seeufer (about 350.000 B.P.) gave us new information about subsistence strategies of lower Paleolithic man. Middle Paleolithic hunting strategies and behavior could be studied on sites like Schweinskopf/Karmelenberg, Wannen, Toenchesberg 2 and Plaidter Hummerich. Our knowledge about Upper Paleolithic living conditions, site organization, technical abilities and art has been enriched by sites like Andernach and Goennersdorf. South of Bingen we have to mention the Middle Paleolithic site of Wallertheim and the Gravettien sites Mainz-Linsenberg and Sprendlingen. All these excavations are well documented. The area between the Neuwied Basin in the north and Wallertheim in the south has not been under regular archaeological investigation for a long time, however.

Besides artifacts that are recovered by systematic excavations, many objects can be found scattered over large areas, especially on the various fossil gravel terraces of the rivers Rhine and Nahe. Usually they are brought to the surface on fields that have been repeatedly ploughed over many years. Since more than 40 years amateur collectors, in cooperation with the Bodendenkmalpflege (curators for archaeological monuments) in Mainz, are working on this surface sites. A scientific evaluation of

these objects has not yet been possible because archaeologists do not have the resources to collect and examine all these findings. For that reason the research project "Paleolithic Land Use in Rheinhessen" was initiated. The principle aim of this project is to get an overview over these, in some cases, huge private collections.

Up to now material from more than 50 different localities has been treated. During this work it turned out that different collectors were working on the same sites, without knowing from each other. These collections have to be brought together again in a way that a scientific evaluation of the whole material becomes possible and manageable. A related problem that appears during studying the different collections is how to make the large inventories available to other archaeologists and other persons with an interest in stone age archaeology. Because the amateur collectors picked up huge amounts of material, with an emphasis on tools and retouched items, the traditional way of drawing all these artifacts is nearly impossible.

Archaeologists and engineers started a joint project to develop a method to make these artifacts available to scientific evaluation without removing them from the private collections. This was a prerequisite to assure the collector's co-operation. The documentation procedure developed relies on 3D scanning. The scan results are visualized in different ways and can be linked to a database and a geographic information system (GIS) which may include information where the objects were picked up and where their materials originally came from. The methods, described below, proved very promising and can be used for any archaeological artifacts and localities.

2. OBJECTS AND MATERIALS

The stone artifacts from Rheinhessen which were studied up to now were all manufactured from local raw materials like quartz, different kinds of Devonian quartzite and Tertiarien quartzite, by hard hammer percussion. That means in general, one rock is hit by another. Normally, a well rounded cobble is used as a hammer stone. The rock from which the flakes are removed is called core. The striking products are the flakes. The best angle for striking stones is under 90°. All flakes have two sides. The dorsal surface represents the outside of the core when the flake was made (which may show cortex or negatives from other flakes removed before as well). The other side of a flake is called the ventral surface. This is the old inner side of the core. Just below the striking platform, which is the surface where the hammer stone struck the core and knocked off the flake, you find on the ventral side the bulb of percussion which represents the energy waves of the flaking blow as they spread into the core. On the whole ventral surface you find wallner waves (ripple marks) which radiate in series of progressively larger arcs from the point of percussion up to the opposite (distal) end of the flake. These waves show the striking direction. On the cores you find the negatives of the flakes which have been removed. The ripple marks in these negatives also allow an analysis of the striking direction and the technique which was used. A normal byproduct from striking stones are small (less than 1,5 cm long) flakes, which are called chips. These small flakes indicate stone striking activities on a site.

Since the first appearance of stone artifacts 2,5 mio. years ago in Africa, the striking technique became step by step more complex. One example for a more complex striking technique is the hand axe, which appears for the first time 1,5 mio. years ago in Africa. The next big step in the development of the stone striking technique is the Levallois technique which is associated with the Middle Palaeolithic. The blade technique is linked with modern humans and is about 40.000 years old. Flakes and blades can be transformed by retouching into different tools like side- and end scrapers, knifes or points. Cores can also be transformed by further treatment to core tools. Detailed analyses of flake and core surfaces give indications on the technical abilities of our prehistoric ancestors.

3. 3D SCANNING

3.1 General remarks

As the objects themselves cannot be examined by all interested parties, very good digital representations have to be made available. In the case of the complicated stone artifacts concerned, this demands a high resolution 3D documentation which comprises the complete surface which consists of sharp edges and larger areas which are relatively flat. Since enormous quantities of objects have to be documented, the method will only be acceptable if it works fast and efficiently.

3.2 Selection of an appropriate scanner

Both 3D scanners already owned by i3mainz, a Mensi S25 and a Leica Cyrax 2500, were not suited for the task since they are designed for much larger objects. Therefore, a new scanner featuring sufficient accuracy and resolution for small object spaces had to be acquired. The ATOS II system, produced by GOM mbH (GOM, 2003), was chosen from a large list of possible candidates with similar features for sub-meter object spaces (i3mainz, 2003).

A main advantage of the system is its modular design which allows various fields of view between about 1 dm³ and 1 m³ when certain components (base, lenses) are exchanged. For the stone age tools, the ATOS II is used in a version that allows to scan a measuring volume of 250 x 250 x 200 mm³. Fringes are projected onto the object's surface (fig. 2b) and recorded by two CCD cameras which are located at both ends of a 600 mm base. The software computes 3D coordinates for up to 1.3 million object points from the camera images with an accuracy of about 0.01 mm. The scanner has a weight of about 4 kg and can be mounted on different types of tripods (fig.1).

Fig. 1: The ATOS II on a heavy tripod

3.3 Scanning procedure

First object position. The ATOS sensor head mounted on a tripod can easily be positioned relative to the stone age artifact which is fixed in special plasticine on a wooden block, where the adhesive ATOS reference points are attached (fig. 2b). During the measurement different fringe patterns are projected onto the artifact (fig. 2b) for some seconds each which are captured by two integrated cameras at either side of the sensor base (fig. 1). Within some more seconds the ATOS software calculates precise 3D coordinates of up to 1.3 million object points.

Fig. 2a: A typical stone artifact.

Fig. 2b: The artifact held in position by plasticine on the base block carrying the ATOS reference points. Fringe patterns are projected for measurement.

During the scan the software checks the ambient illumination and possible relative movements between scanner and object because these can have an influence on the accuracy of the measurement. If one of these checks indicates problems, the software gives a warning and the scan can be repeated. Because of the critical influences of light and stability, the best place for measurements based on light pattern triangulation is a dark room with a solid floor. Surface reflectivity may cause problems, too. If the material is too shiny or transparent, the projected fringe patterns may not be identified correctly by the

cameras. In the case of stones, white powders that can be sprayed on the surface and washed of with water afterwards can be used without causing any harm to these objects.

The artifact is scanned with one end fixed by the plasticine. The result of the measurement is directly displayed (fig. 3, left). By rotating the object, further scans can be acquired without changing the relative position of object and reference points. Usually, 5 to 7 individual views are needed to record the complete visible surface in the first object position.

For a complete representation the individual views are merged into a single data set. With an automatic determination of the current sensor position, the system can transform the individual measurements into a common object coordinate system using the detected ATOS reference points. The result is the 3D mesh for the first object position. The part of the artifact covered by the plasticine must be measured subsequently in a second object position.

Second object position. In order to allow scanning for the second position of the object, it is turned around and the other side is now held in the plasticine. Again, several single scans are acquired and combined to the mesh for the second position.
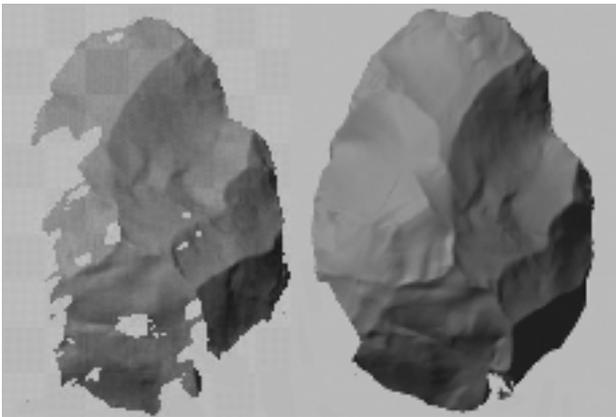

Fig. 3. Left: Result of a single scan.
Right: Combination of different scans.

Now, the two meshes (first and second object position) have to be merged into one. Since there are no common ATOS reference marks available in this case, four or more common points have to be identified interactively on the meshed surface. In most cases, this is a very time consuming process; often it is impossible at all. Two-dimensional points like color marks can not be identified in the 3D views of the surfaces. After many experiments, including the construction of swiveling clamps, it was decided to mark four very small three-dimensional targets on flat parts of the object. Toothpaste proved to be an ideal material since it has the right consistency, high reflectivity and it can be removed without any problems after the measurement process. Thus, the identical points can be identified easily and quickly because the tooth paste peaks' position is known beforehand and 3D features can be recognized easily in the mesh.

After this pre-registration which merges the two meshes together, an automatic 'Best Fit' registration improves the result and provides the final set of data for the whole artifact as an ASCII point cloud or in a polygon mesh according to the STL format. If there are some small insignificant holes left, these can easily be filled by the software. The toothpaste peaks which are still on the mesh are cut out and removed. The resulting holes

can be filled without much quality loss since the peaks are very small and were intentionally placed in flat insignificant parts of the object. This completes the scanning procedure, and a virtual 3D model of the object is now available (fig. 4). The whole procedure which includes scanning, registration, meshing and hole filling can be accomplished with the hard- and software supplied by GOM and takes less than 45 minutes per artifact.

Fig. 4: Virtual 3D copy of a stone age artifact

3.4 Thinning methods and storage

The acquired virtual 3D model shows a very high point density resulting in large file sizes. This density is necessary to document the sharp edges; in parts with small and/or regular curvature, point density can be reduced considerably, however, without any recognizable quality loss. Using the ATOS software itself or other software products like Geomagic Studio or qslim the mesh can be thinned intelligently. With qslim, for example, we could often reduce the file sizes by about 50%, with no recognizable differences when viewing the model. Of course, the potential of thinning depends a lot on the structure of the stone artifact's elements. For the storage of the results the common STL file format is used. It can be read by most 3D viewers and 3D processing programs.

4. VISUALIZATION

4.1 3D viewers for 3D inspection

When the measurement is complete and a 3D result is stored, archaeologists can view the data on a monitor (fig. 4). For this purpose, a viewer is necessary which shows the 3D result. With such a program (such as SolidView which is freeware in its light version), anyone can view the artifact and change viewing angles and lighting interactively. The virtual model can easily be inspected from all sides, much in the same way as the original stone object would be examined.

4.2 Edge based visualization

In a diploma thesis at FH Mainz (Tschoepe 2003) an attempt was made to classify and visualize local curvature on the object. After a triangular mesh of the object's surface is accomplished, every individual triangle can be furnished with an own texture when the OBJ format is used. The computer program developed

computes the differences between a triangle's normal and the angles of the normals of neighboring triangles and uses it to classify the local curvature. The intensity of the triangle's texture is then created depending on the class of the local curvature. Since concave and convex curvatures are encountered, two different colors are used. As color printing was not possible for this paper, figure 6 cannot really show the fine results achievable with this method. The curvature shaded object is still a 3D object and can be examined in a 3D viewer. When selected 2D views are generated, these can replace the hand drawn figures usually produced by archaeologists for publications. The outlines, as described in the following section (4.3) may be added.
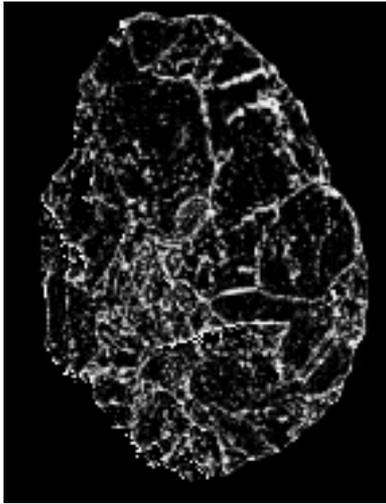
Fig. 5: Same object as in fig. 4,
here shaded depending on local curvature
(two different colors are used for convex and concave parts
which cannot be distinguished in this gray tone printing).

4.3 Object outlines in 2D visualizations

Since manually capturing outlines for a 2D view is very tedious, an automatic procedure was developed at i3mainz. It detects all lines on a digital 3D model where the observation vector and the object normals are perpendicular. For a convex body they can also be called silhouette or contour.
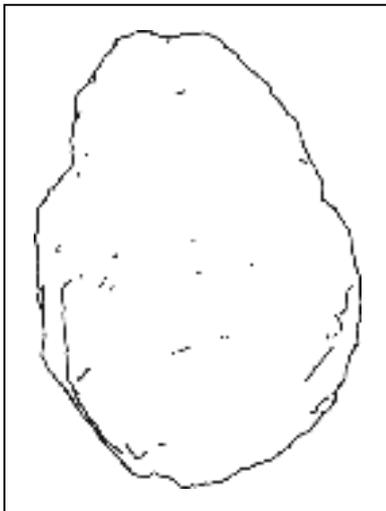

Fig. 6: Automatically generated contour (silhoutte) lines

As 3D objects based upon triangular meshes are used, outlines are made up from all triangle edges belonging to front-facing as well as back-facing triangles. If only front-facing triangles are considered, outlines correspond to the outer edges of the triangular mesh. Thus, finding contour lines consists of the following steps:

- Choosing the desired 2D (parallel) projection.
- Reading front-facing triangles.
- Finding edges, belonging to one single triangle only.

Since occlusions have to be considered, a visibility test for all (potential) outlines has to be performed, eliminating those lines that are hidden behind object parts closer to the observer.

4.4 3D viewer for interactive inspection in the Internet

Since users at distant locations may want to inspect the virtual collection, the data should be available in the Internet, too. For this purpose an interactive visualization tool was developed. Various alternatives were considered for the technology. Plug-in technologies (mostly proprietary tools) provide quick rendering solutions, optimized for the Internet usage. Alternatively, an approach based on Java3D was considered and finally chosen. This provided the necessary options for the integration of database access. In addition, the tool can be used as a stand-alone application as well as an applet running in the Internet. Since further investigations for optimizing the visualization are required, the Java3D interface provides the appropriate means.
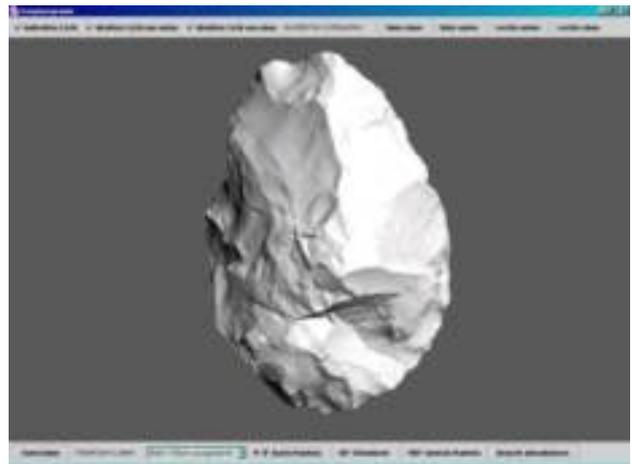

Fig. 7: Java3D visualization tool for the Internet
using a flat shading approach.

Presently available shading algorithms, for instance Gouraud-Shading (Foley et. al., 1990), provide a good basis for 3D visualization including an intuitive depth perception. Those standard algorithms are supported by Java3D and also by most graphics hardware products. The shading calculations of those algorithms depend on the normal vectors of the surfaces. In the case of the Gouraud shading, the normal vector of the surfaces and the normal vectors at each point are used. This leads to smooth transitions between the polygons. In the case of visualizing stone artifacts, this would eventually eliminate important edge information of the stone. This, of course, depends on the resolution of the data set as well. In order to avoid the elimination of this information, our first approach was to use a flat shading model instead, which uses only the normal vectors of the surfaces. This, of course, sharpened the edges but the overall appearance of the artifact deteriorated (see fig. 7, which

presents the Java3D visualization tool using the flat shading approach, as outlined above).

At the current stage, the tool allows Internet based visualization with standard means. However, further investigations are necessary to provide a superior presentation, enabling a better understanding of the artifact by the user and limiting the data to be transferred over the network at the same time. Edge visualization and contours might be a good approach here, too. For a thorough inspection, the complete set of data is necessary, however. Thus, the Internet may serve to inspect the collection and select those pieces for which a complete set of data will be ordered.

5. DATABASE DESIGN AND GIS CONCEPT

In addition to the scanning data describing the geometry of the artifacts, further information concerning the artifacts are stored in a database. Due to the similarity of the findings, the database design can be kept rather simple. The main table of the relational database holds one record for each artifact.

The items can be classified into different categories:
- Items of identification like the identification number.
- Person keeping the artifact, place where it is kept, and inventory number.
- Basic description (type of artifact, material, weight).
- Link to the scanning data and derived graphical products like sections, views, etc.
- Geometric quantities derived from the scanning data, like volume, surface, unit weight, etc.
- Information about the place where it was found (easting, northing, height, accuracy of position and height).
- Information on the actual condition (recent damages, traces of fire, etc.).
- Further textual information.

Additional tables may contain, for example, classes of types of artifacts, damages, etc., to which codes in the main table are pointing. The main table keeps all major information describing the single artifact and links to further information like the 3D model and views. It can be used for all kinds of queries using standard SQL format.

The availability of information concerning the place of finding the artifacts allows using basic GIS functionality. The quality of the recorded coordinates for these places may differ considerably. Some findings can be referenced just to a certain parcel where others may have an absolute accuracy of better than 10 meters since GPS was used when the artifacts were collected. Therefore it is mandatory to store and use information about the accuracy of these observations and take it into account when analyzing or comparing spatial information. The spatial information can be used in different ways, a simple one is the plotting of distribution maps of the findings, resulting from a database query, on the fly. Combinations with current topographic maps can assist in orientation. Using further external information like e.g. DEMs, geological or hydrological maps in combination with the distribution of the artifacts and the functionality of a GIS allow further conclusions about the history of the findings and their usage by man.

6. CONCLUSIONS

Considerable numbers of artifacts can be documented with high accuracy and resolution when the methods described are used. Virtual artifact collections can be documented completely, even if the artifacts are stored at different places, including objects that were considered as being unretouched pieces. The virtual collection thus achieved can be distributed easily on storage media such as CD ROMs or even through the Internet. It can be examined by anybody and compared to any real or virtual artifacts of similar origin.

All visualization products are results of automatic and objective procedures, thus avoiding the individual subjective interpretation which is inevitably part of hand drawn figures.

8. REFERENCES

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